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R&D TESTING OF HULL MECHANICAL AND ELECTRICAL SYSTEMS  
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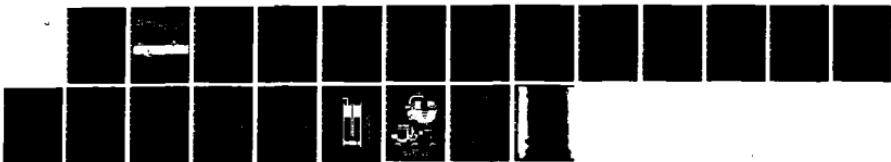
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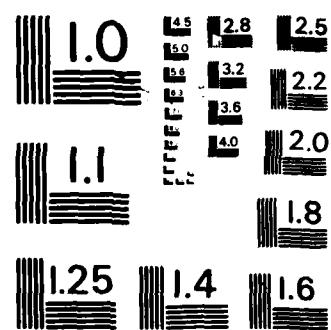
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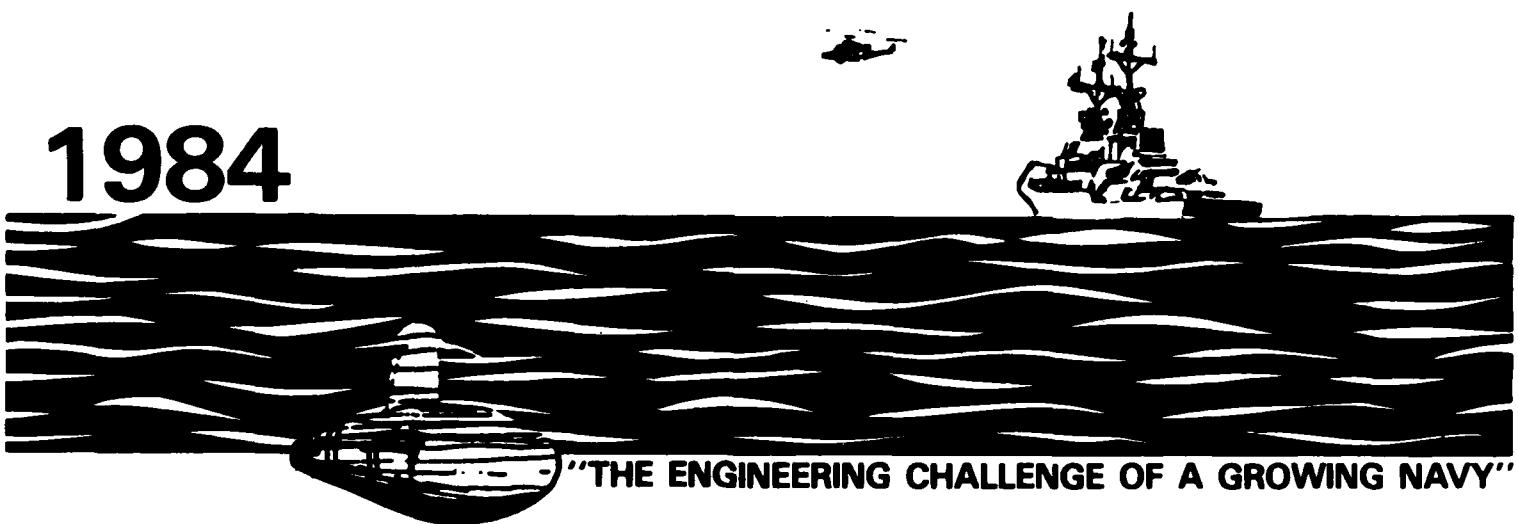
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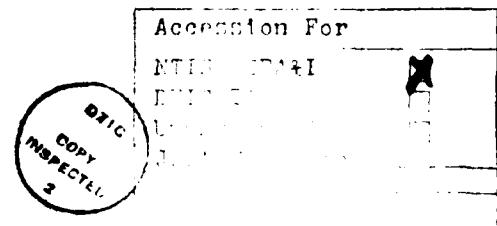
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R&D TESTING OF HULL, MECHANICAL AND ELECTRICAL SYSTEMS

*Stuart D. Rednor*

R&D TESTING OF HULL, MECHANICAL, AND ELECTRICAL SYSTEMS

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### ABSTRACT

Adequate testing prior to Operational Test and Evaluation and subsequent introduction to the end user is of critical importance in the development of effective shipboard systems. The same rigor and discipline that the Electronics Systems engineers place on the testing of their equipment should also be applied in the development of HM&E systems. Increasing demands are being placed on the engineers responsible for development of new shipboard equipment and systems for their improved efficiency, reliability, maintainability, performance, and reduced weight. These competing demands emphasize the necessity for careful test planning.

This paper describes the essential elements of adequate planning for Test and Evaluation (T&E) of new ship systems. These elements include the following: (1) the relationship between T&E and the acquisition process; (2) adequate technical scope and realistic scheduling of T&E; (3) realistic funding projections; and (4) good working relationships with Government T&E activities outside headquarters such as labs, field activities and the Test Facility. Also discussed are a number of recent HM&E R&D programs to illustrate the different types of T&E phases such as factory testing, land-based test site testing, and shipboard testing.

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LIST OF ABBREVIATIONS/ACRONYMS

ACAT	Acquisition Category
ADM	Advanced Development Model
AFP	Approval for Full Production
ALP	Approval for Limited Production
DFM	Diesel Fuel Marine
DT&E	Development Test and Evaluation
D&V	Demonstration and Validation
EDM	Engineering Development Model (Pre-production Prototype)
EOS	Enclosed Operating Station (in Propulsion Plants)
FOT&E	Follow-on Operational Test and Evaluation
FSD	Full-Scale Development
HM&E	Hull, Mechanical, and Electrical
LBTS	Land-Based Test Site
LOS	Local Operating Station (in Propulsion Plants)
MTBF	Mean-Time-Between-Failures
OPEVAL	Operational Evaluation
OTD	Operational Test Director
OT&E	Operational Test and Evaluation
QA	Quality Assurance
R&D	Research and Development
RDT&E	Research, Development, Test and Evaluation (Appropriation)
RM&A	Reliability, Maintainability, and Availability
RO	Reverse Osmosis
SCCP	Self Cleaning Centrifugal (DFM) Purifier
SVPC	Standard Vertical Package Conveyor
T&E	Test and Evaluation
TECHEVAL	Technical Evaluation
TEMP	Test and Evaluation Master Plan
UNREP	Underway Replenishment
VCD	Vapor Compression Distilling Unit

## I. INTRODUCTION

The acquisition of new systems within the Government has evolved over the past two decades in such a way that Test and Evaluation (T&E) now plays a more significant role in the process. In the early 1960's, in response to rapid technological advances, the Government instituted an acquisition policy known as "Total Package Procurement". This policy involved going out to industry with a single contract for the research and development (R&D) and production phases. The contractor would be given broad generalities as to the performance the Government expected. Later, the contractor would deliver the production units to Government at the completion of the contract. This method resulted in increased cost, schedule and performance risks. In the early 1970's the Government replaced the Total Package approach with "Milestone Procurement". In Milestone Procurement, funds are authorized and contracts are awarded in phases preceded by discrete decision points. A critical input to these decisions is the results of T&E. This approach, also known as "Try Before Buy", works as follows: you do not commit additional funds or proceed to the next program phase unless thorough system testing demonstrates acceptable performance. These policies on T&E were spelled out both in Federal Statute and Government Directives. Specifically, the U.S. Congress stated the importance of Operational T&E (OT&E) in Chapter 4 of Title 10, U.S. Code which states that the Government must submit to Congress each calendar year a written report for each system for which any funds for procurement are requested in that budget. The report includes data on operational testing and evaluation for each system.

One of the Government Directives states:

"Test and Evaluation shall begin as early as possible and be conducted throughout the system acquisition process to assess and reduce acquisition risks and to estimate the operational effectiveness and operational suitability of the system being developed."

This Directive also requires that each Department have its own OT&E agency, independent of both the end user and the developing activity, who is responsible for planning, conducting and reporting on OT&E. Within the Government this independent agency is the Test Facility. This organization specifically concentrates on the operational suitability and effectiveness of the system being evaluated from an operator's point of view. Most of the R&D programs under the direction of the Government involve the two basic types of T&E, that is Development T&E (DT&E) and OT&E.

The DT&E and OT&E test phases form the building blocks of the acquisition programs from initial R&D through production and deployment. The need to adequately plan for these phases is of tantamount importance to the success of the program. The paper discusses in general terms typical system acquisition program phasing as it relates to T&E. The two main types of T&E are described. The case is made as to why Hull, Mechanical, and Electrical (HM&E) systems should be tested as thoroughly as electronics systems. Recommended T&E program planning elements are described including the following: adequate technical scope, sufficient at-sea DT&E prior to Operational Evaluation (OPEVAL), realistic budget estimates and program scheduling, and good relations between the program office and the test activities in the field. After the recipe for good T&E program planning, the paper gives examples of recent HM&E system R&D programs to illustrate the different types of T&E such as factory, land-based and shipboard testing. The examples include: Vapor Compression Distilling Unit, Reverse Osmosis Desalination Plant, Self Cleaning Centrifugal Diesel Fuel Marine Purifier, Diesel Propulsion System, and Standard Vertical Package Conveyor.

## II. T&E AND THE ACQUISITION PROCESS

As described in the latest policy documents on T&E and acquisition procedures, there are three basic program milestones. As shown in Figure 1 (this is a typical system acquisition program structure), Milestone I precedes the demonstration and validation phase, Milestone II precedes the full-scale development phase, followed by Milestone III, which precedes production. The program should be structured such that the T&E phases and results feed into the decision making process at each of the key milestones. The decision as to whether to continue funding the program and proceed to the next phase should be based on the achievement of preset performance thresholds as verified by adequate T&E.

For most HM&E systems, program initiation begins with authorization of adequate Research, Development, Test and Evaluation (RDT&E) funding to enter the demonstration and validation (D&V) phase. Since most of these systems are Acquisition Category (ACAT) III, IVT and IVM programs, Milestone I will normally be eliminated; RDT&E funding approval authorizes entry into the D&V phase. In order to focus higher management attention on higher priority programs, the Government established four ACATs, each with a different echelon assigned as the final authority at milestone reviews. Generally, ACATs are assigned according to the overall R&D and production costs of the program. However, for ACAT III and below, there are other determinants. ACAT IV programs are divided into ACAT IVTs, which include OT&E and ACAT IVMs which do not. Most HM&E programs do not have a formal Milestone II. However, the decision to proceed into full-scale development (FSD) should be made by some type of in-house program review. In all programs, regardless of the ACAT, Milestone III is a formal decision point as to whether the system is ready for full production. Although there are cases when the Government has to plan for an interim approval of limited production (ALP), the Government generally

structures their programs with the intention of receiving approval for full production (AFP) at the completion of the FSD phase.

As stated before, T&E has become an integral part of the systems acquisition process. The T&E conducted for the Government to demonstrate design and technical requirements is known as DT&E and is usually conducted by hardware contractors, subcontractors, Government labs and field activities. OT&E is conducted by the Test Facility to estimate a system's operational effectiveness and suitability. Operational effectiveness is the ability of a system to perform its mission in the intended environment. Operational suitability is the ability to deploy a system considering reliability, maintainability, availability, logistics supportability, compatibility, interoperability, training, safety, human factors, and transportability. The purpose of testing during the D&V phase is to demonstrate that design risks have been identified and minimized and is normally conducted using Advanced Development Models (ADM) at the subsystem/component level. Testing conducted during FSD normally involves a pre-production prototype or Engineering Development Model (EDM) to demonstrate achievement of performance and technical requirements (DT&E) and to demonstrate operational effectiveness and suitability (OT&E).

Many times testing is continued after the Milestone III production decision has been made. DT&E after the production decision is conducted to verify the effectiveness of modifications and redesigns made as a result of earlier testing, such as Technical Evaluation (TECHEVAL), OPEVAL or production line testing. It can also be conducted to verify that the production system does not display unexpected weaknesses or deficiencies injected by the transition to a full production line manufacture/assembly process. DT&E is used to demonstrate a system's readiness to enter Follow-on Operational Test and Evaluation (FOT&E) phases. The Test Facility usually plans for FOT&E to evaluate correction of deficiencies identified during earlier testing as well as to conduct some aspect of OT&E not investigated prior to the production decision.

### **III. WHY WE NEED ADEQUATE TESTING OF HM&E SYSTEMS**

Up until recently, the emphasis on thorough technical and at-sea development testing has been more visible in the electronics systems programs. Thorough testing of pumps, purifiers, distillers, and shipboard machinery is just as important as testing the complex electronic systems being developed as part of major new systems.

There have been a number of recent cases where the HM&E program managers/engineers were not planning to conduct at-sea DT&E testing prior to OPEVAL. After careful re-consideration, these programs modified their test planning to include sufficient at-sea T&E. HM&E systems must be put through the same rigor and discipline that we place on our new electronics systems.

In comparing a number of examples of HM&E and electronics systems programs several observations can be made. One is that the OPEVALs of HM&E systems are usually much longer in their shipboard testing, that is 8 months to 1 year at sea, whereas electronics system OPEVALs are frequently 1 to 2 months. One of the driving factors is that HM&E mean-time-between-failures (MTBF) values are usually much higher and as a result, their OPEVALs are longer to enable the Test Facility verify reliability and durability of the machinery in the shipboard environment. In contrast, the operational testing of electronics systems is more focused toward running the system through a representative number of modes of operational scenarios to thoroughly test out the hardware and computer software integration; this can usually be done in much less time than in the case of testing shipboard machinery.

Knowing that the OPEVALs of HM&E systems will involve up to 12 months at-sea operation aboard a ship, we need to adequately plan for our DT&E through TECHEVAL to ensure a successful OPEVAL. But this isn't the only reason. While rigorous system testing at a Land-Based Test Site (LBTS) allows the system to be run through a wide range of operating conditions and test variables prior to ship installation, there are shipboard conditions that can only be examined in an at-sea situation. (This is not to say LBTS testing is not important; it is that thorough LBTS evolutions should be followed by rigorous at-sea DT&E testing.) Examples of this are: (1) the performance of the system's auxiliaries (ship interfacing systems) may vary considerably under actual shipboard conditions in an uncontrollable, non-repeatable way (LBTS allows testing under many different conditions but it is highly repeatable and controllable); (2) system performance may be affected by ship's movement (pitch and roll) and there is no practical way you can simulate this for HM&E at an LBTS; (3) actual shipboard installation problems and accessibility and maintainability concerns can much better be addressed with shipboard testing; while you can approximate ship arrangements and space limitations at an LBTS, the real test of accessibility and maintainability of HM&E can only be fully proven out on the ship, (4) While an LBTS provides an excellent test bed to address ship interface concerns, even the best LBTS will not include every physical and functional interface that the system will see on the ship.

Examples of where some non-shipboard test limitations exist are the propulsion system land-based test sites such as those being operated by the Government. The propulsion engine intake air and cooling water temperatures are determined by the weather conditions at the test site area and the temperature of the river adjacent to the site. Aboard ship, in worldwide

operations, the propulsion plants will see a wide range of ambient air and seawater temperatures and atmospheric pressures. A large number of combinations of these parameters is possible at sea. Another example is the limitation presented by the use of waterbrakes to simulate loads on propulsion shafting at an LBTS. While a waterbrake provides an excellent means of varying shaft loading, it can only approximate what the propulsion system will experience at sea. Aboard ship it is possible for a propeller to come out of the water in heavy seas and result in a sudden load change on the propeller shaft. There is a limited slew-rate or a limit to how rapidly you can vary the shaft loading with a waterbrake. Therefore, sudden load changes cannot be simulated by a waterbrake. An example of where ship pitch and roll effects require proofing at sea is the safety features and interlocks going into a new item of deck machinery such as the package conveyor described in Section V. While these conveyor subsystems are being designed and tested at an LBTS, the validation of their performance during high sea-states can only be done by observing equipment operation at sea.

The DT&E test phases must cover "all of the bases" including the demonstration of design, technical, and performance requirements as well as the logistics supportability, compatibility, interoperability, safety, electromagnetic compatibility, human factors, and reliability, maintainability and availability (RM&A). The DT&E must culminate in TECHEVAL which should include sufficient time at sea with the intended user operating and maintaining the equipment. Installation problems, quality assurance (QA) and design deficiencies uncovered during TECHEVAL must be addressed and corrected prior to the start of OPEVAL. This includes problems found in the documentation also. In the next section of this paper an outline is presented that describes the essential elements of good T&E planning.

#### **IV. RECOMMENDED PRACTICES FOR GOOD T&E PLANNING**

Experience has shown that there are a number of items essential to good test program planning. They are listed below:

- o Start early
- o Don't be too success oriented
- o Conduct thorough factory and land-based testing
- o Have at-sea TECHEVAL
- o Test logistics as well as design
- o Maintain good communication with T&E activities

Early planning of the test program is vital to its success. This requires involvement from all participants, particularly the program manager, project engineer, field activities and the Test Facility. The program manager should begin working on the initial draft of a Test and Evaluation Master Plan (TEMP)

in conjunction with the Test Facility as soon after program initiation as possible. For most ACAT III and all IVT and IVM, programs the TEMP serves as the single top level management document containing performance requirements for the system under development. (ACAT IVM TEMPs do not involve the Test Facility and therefore do not have an OT&E section).

Every program has different degrees of technical, design and operational risk associated with it. The planning for adequate T&E should be tailored to the particular risks of the program. Some programs may involve simply an improvement over an existing design concept; others may involve a significantly new concept. The early test program planning must be oriented towards progressive risk reduction. When the conceptual design is in hand, the details of the engineering design package need to be proven out. Most of the HM&E programs have risks associated with the detailed engineer's design during the FSD phase as opposed to risks involving the concept itself. Hidden design deficiencies at the component level may not show up until later DT&E of the EDMs such as TECHEVAL. Examples of this are an underrated motor power, incorrect piping or valving materials, and a resistor of insufficient power rating for the application. Even the best theoretical engineering design process will miss some of these; this is why thorough testing is important.

One of the most common program manager's mistakes is being too success oriented. If all the elements of your test program planning including budget, schedule, test phasing and test scope are based on successes at every point, you will inevitably have problems. Many of the larger HM&E systems involve a number of equipment items and subsystems. Sometimes the scheduling of equipment delivery is too optimistic; if your delivery dates slip, so will your test dates. Lengths of planned test phases are frequently too short; sufficient time should be allowed for delays, failures and correction. It is essential to build in enough slack in your funding and scheduling to anticipate a reasonable amount of unforeseen problems and to allow for correction of problems uncovered during testing.

As we have discussed in this section as well as the previous one, thorough DT&E prior to OPEVAL is important. The DT&E evolutions beginning with the contractor's testing of the pre-prototype unit (ADM), proceeding through pre-production prototype (EDM) testing at the factory and LBTS and finally, TECHEVAL aboard the ship need to be problem-solving oriented and result in progressive risk reduction. ADM testing should give the program manager confidence that the design concept will work and that the technology is available to build a full-scale model. EDM testing including TECHEVAL needs to verify attainment of all technical, performance, and design objectives at the component and subsystem levels and interfaces and finally the total system within its shipboard environment. TECHEVAL should include crew training in preparation for OPEVAL and should include a period of time where the intended users are operating and maintaining the system on their own, unassisted by contractors or Government engineers. In addition, TECHEVAL should involve more than a dockside installation and checkout and system's operability

testing; as a minimum it should include 1 to 3 months at-sea time under typical operations.

Many program managers do a careful job of designing and testing out their hardware from an engineering point of view; however the same level of attention needs to be paid to logistics support aspects of the system. While it is true that a lot of the logistics support documentation and sparing will be refined between R&D and production, we would be helping out the end user if we did our job to get the logistics squared away as early as possible. The point here is that the DT&E needs to address testing of logistics products as well as the system's design. Also, successful testing and verification of the logistics products during TECHEVAL is mandatory to certify that the system is ready for OPEVAL.

The last item discussed is probably the most important one. It is extremely important to maintain good working relations with all parties involved in an R&D program. One of the biggest shortfalls of programs in the past has been a sometimes adversarial relationship between the program engineers and the Test Facility personnel. Much of this can be avoided if you involve the Operational Test Director (OTD) early in the test planning process. Invite him to your program reviews, design reviews, factory test sites and LBTS. A continuing, open dialogue will benefit both participants. The technical community benefits from someone with operator insights providing inputs to their program and the OTD benefits and can do his job better if he understands the technical aspects and design evolution of the system. This comment not only applies to the Test Facility. Many times we develop a "them and us" mentality when dealing with the labs, R&D centers, and engineering activities. While the program manager may feel uncomfortable with the differing views and positions coming from all of these players, this type of dialogue can only help the program in the long run.

## **V. RECENT HM&E SYSTEM R&D PROGRAMS**

This section of the paper covers a number of recent HM&E systems that illustrate examples of particularly well planned and structured programs.

### **Vapor Compression Distilling Unit**

The Vapor Compression Distilling (VCD) Unit is an electrically operated unit designed to supply fresh water in the absence of a steam heat source. As shown in Figure 2, this unit operates on a closed cycle system which involves heating seawater to steam. The steam is then drawn off and condensed by means of a centrifugal compressor. Distillate is then piped off for shipboard use. The remaining brine is dumped overboard. The purpose of the unit is to produce high quality distillate from seawater for surface ships. The installation will consist of 2 units per ship.

Initial DT&E, DT-IIA was conducted on a VCD unit at the manufacturer's LBTS. The objectives of this testing were to assess the unit's ability to meet its technical requirements and operational characteristics. DT-IIB involved testing the same unit used for DT-IIA aboard a ship to test the installed unit's ability to meet its requirements in a shipboard environment. The Test Facility conducted an Initial OT&E (IOT&E) shipboard evaluation of the same unit used in DT-IIB. DT-IIC was recently completed at the manufacturer's LBTS and involved performance testing of the Government specified, unit. DT-IID completed in 1983, involved environmental testing of the first pilot production unit built to Government Specifications. DT-IIE is TECHEVAL and is currently taking place aboard a ship.

#### Reverse Osmosis Desalination Plant

The objective of the Reverse Osmosis Desalination Plant Program is to develop an electrically powered desalination plant for non-steam powered ships. The system is a modular two-stage desalination plant (see Figure 3) using the reverse osmosis (RO) process for removing the salt from seawater. The modules have semi-permeable hollow fiber membranes through which the water is forced under pressure for desalination. Other components include a high pressure, electrically driven pump and prefiltration and chlorination equipment to remove silt and marine life. The purpose of the RO desalination plant is to produce potable and boiler feed quality water from seawater for surface ships.

The initial DT&E of RO concept began almost ten years ago. In 1973 RO modules were obtained from the Department of Interior. Testing with artificial and natural seawater indicated a need for further study in the area of seawater pretreatment. A model RO plant was built by a contractor and tested under Government direction from 1973 to 1976 to evaluate various seawater pretreatment techniques. As a result of earlier testing, a prototype single-stage, hollow fiber RO prototype shipboard unit was constructed and tested first in the laboratory (DT-IA) then later on a barge (DT-IB) under direction of the R&D Center. Overall, the testing produced good results and the decision was made to build an RO plant (two-stage pre-production prototype). The plant, consisting of a pretreatment system and first and second membrane stages, has operated since 1981 (DT-IC) aboard a ship. To date these results have been favorable. The unit installed aboard the ship will provide data to the design package for the unit which is currently being designed to Government Specifications and further testing.

### Self Cleaning Centrifugal Diesel Fuel Marine Purifier

The Self Cleaning Centrifugal Diesel Fuel Marine (DFM) Purifier (SCCP) (See Figure 4) is an improved fuel purifier which has a built-in capability to clean bowl solids by the means of a water shoot cycle thus eliminating the need for frequent manual cleaning. The SCCP will provide purified DFM for use in propulsion plants such as LM-2500 gas turbines where fuel purity is essential. The purifier receives fuel from the ship's fuel transfer pumps and subjects it to a centrifugal force of about 3,000 G's. The entrained free water and solids are separated, the purified fuel delivered to the fuel service tank and effluent water discharged to a drain tank.

Initial development testing, DT-I took place from 1975-1977, proved feasibility of shipboard use of an SCCP. DT-IIA phase 1 involved procurement and manufacturer's testing of a hardened SCCP, Alfa Laval WHPX 513 Model, later designated USPX-413. DT-IIA phase 2 involved testing at the Government's LBTS. TECHEVAL (DT-IIB) aboard a ship lasted about 3 months. The system is currently undergoing OPEVAL.

### Diesel Propulsion System

The propulsion plant consists of four V block 16 cylinder main propulsion diesel engines paired up through two twin-pinion reduction gears to drive two controllable-pitch propellers. The control system provides for control from the bridge, enclosed operating stations (EOS), and local operating stations (LOS). An LBTS was constructed at an engineering test facility consisting of one shaft set of propulsion plant equipment which simulated in arrangement and operation the equipment to be installed in the ship. The purpose of the testing at the LBTS is to verify system integration and to identify and resolve design or technical problems prior to delivery of the lead ship. The intention is to reduce the risk of expensive post-delivery ripouts of and changes to the shipboard propulsion system installation. To date, most of the DT&E has been completed.

The decision to test and evaluate extensively the propulsion plant of the ship was sound. The class involves a number of ships and hence the LBTS T&E is justified; this is the first time medium-speed diesels are being used as a ship's main propulsion system. Experience has shown that new propulsion systems frequently have unproven control systems and this can be a risk area. Evaluation of control system integration at an LBTS can reduce these risks considerably. Also, propulsion systems may not function immediately as designed when the hardware, which has been developed and manufactured at a number of different places, are brought together for the first time aboard ship.

The information gathered to date from problems discovered during the LBTS installation and checkout, acceptance testing and DT&E has provided valuable lessons learned for the benefit of the shipboard installation. Numerous documentation and design deficiencies were discovered early enough so that engineering changes could be picked up by the lead ship construction effort in a timely manner. Problems identified during OT&E (Operational Demonstration) at the LBTS concerning operability, maintainability and logistic supportability will continue to provide lessons learned data to the shipbuilding program.

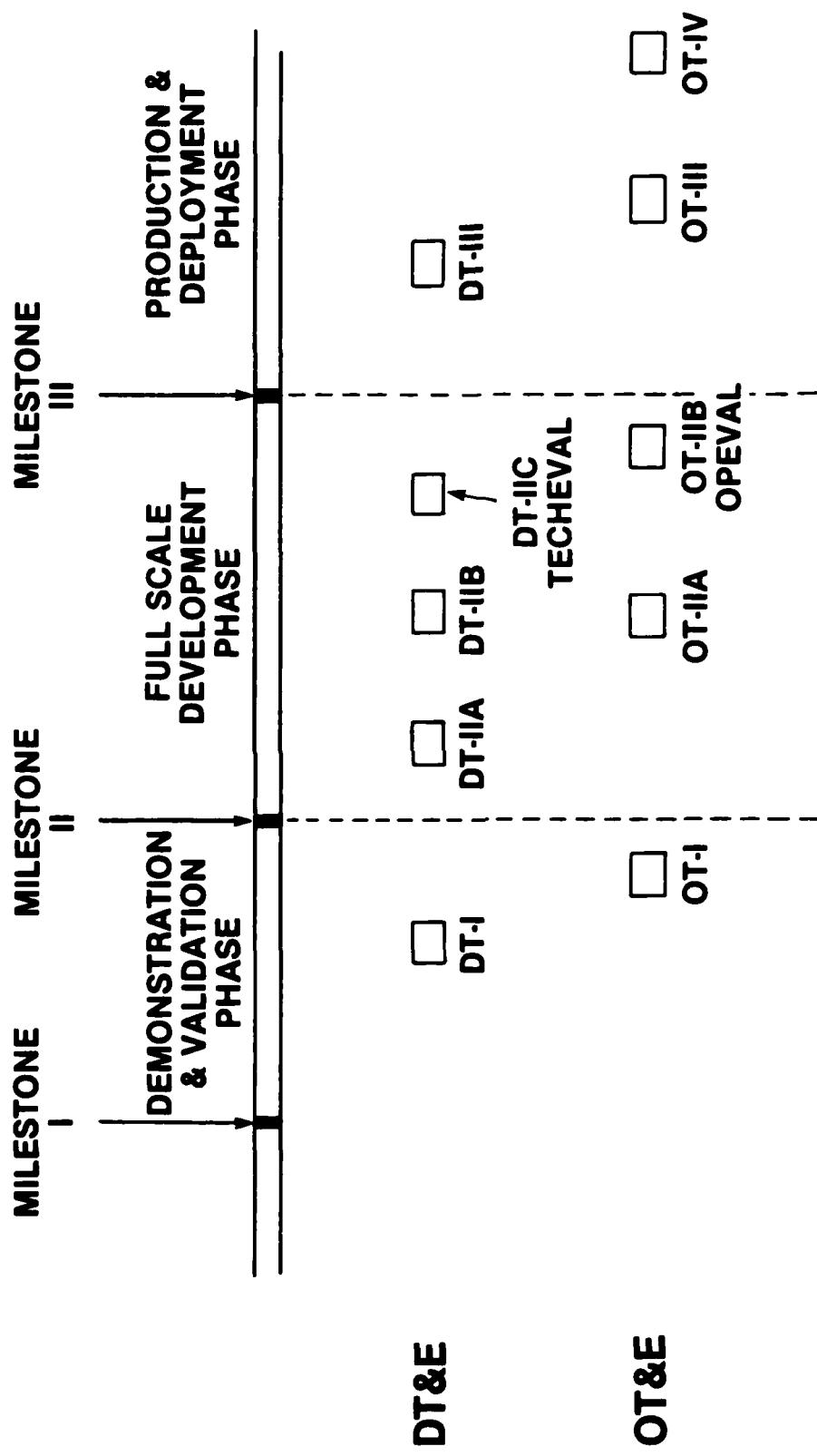
#### Standard Vertical Package Conveyor

The Standard Vertical Package Conveyor (SVPC) will provide a standardized, safe means for rapid package movement between ship decks and for use in underway replenishment operations. The prototype SVPC, rated at 100 pounds per tray (See Figure 5), is 40'-10" between sprocket centers with four door openings corresponding to four deck levels. It consists of a trunk, doors, guards, supporting framework, trays, carrier chains, tray guide tracks, loading platforms, load-unload devices, controllers, control stations, and electrical drive equipment. The side of each tray is attached to an endless carrier chain which is powered by a drive unit through two drive chains.

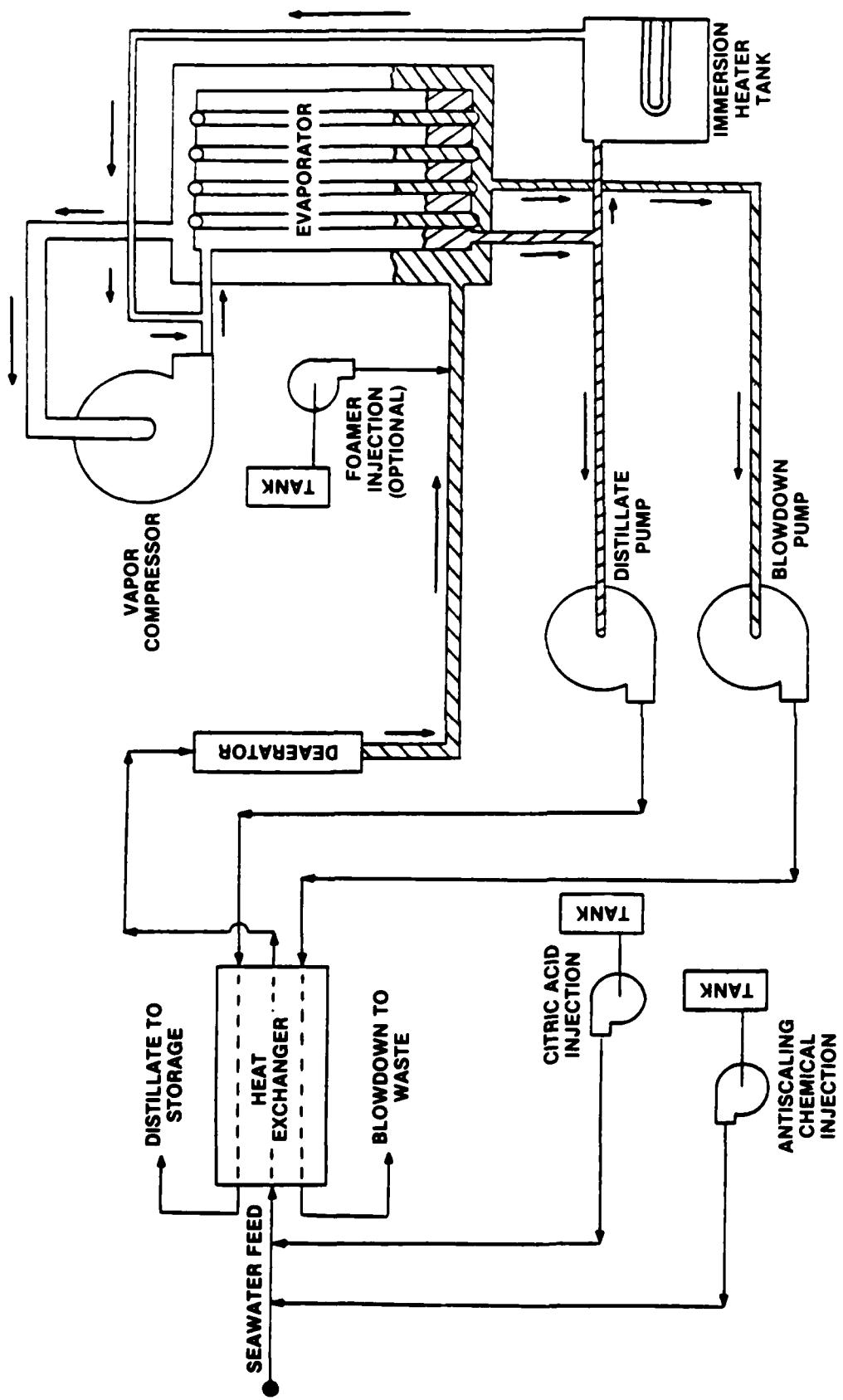
Initial DT&E to date (through DT-IIA) has consisted of design, fabrication and factory testing of the prototype SVPC. The manufacturer has performed static and dynamic overload testing and selected maintenance actions as well as 150 hour Reliability and Maintainability testing. Two prototype conveyors were delivered to an engineering test facility. The facility has modified the prototypes by the addition of safety interlock switches and doors at the loading and unloading stations. DT-IIB will consist of two phases, that is an LBTS evaluation followed by TECHEVAL testing aboard a ship. Upon successful completion of shipboard TECHEVAL, OT-IIA will commence.

#### 6. SUMMARY

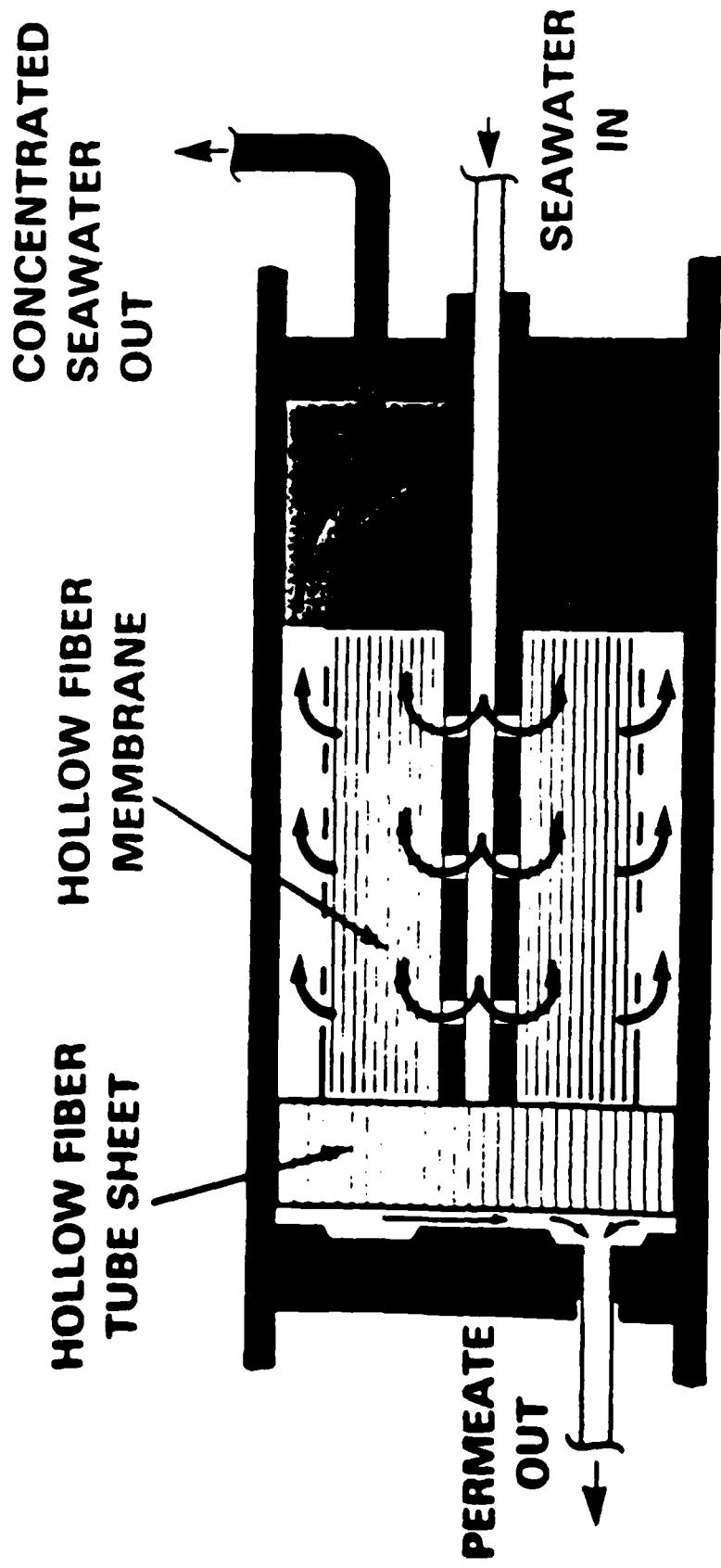
The paper was written to express the author's concern that more attention needs to be given to test and evaluation of HM&E systems. The case was made as to why at-sea testing of HM&E systems is just as critical as in the case of electronics systems. A number of major recommendations were provided to help program managers and engineers get started on good T&E programs. The program examples cited gives evidence of where testing has been given the proper level of attention.



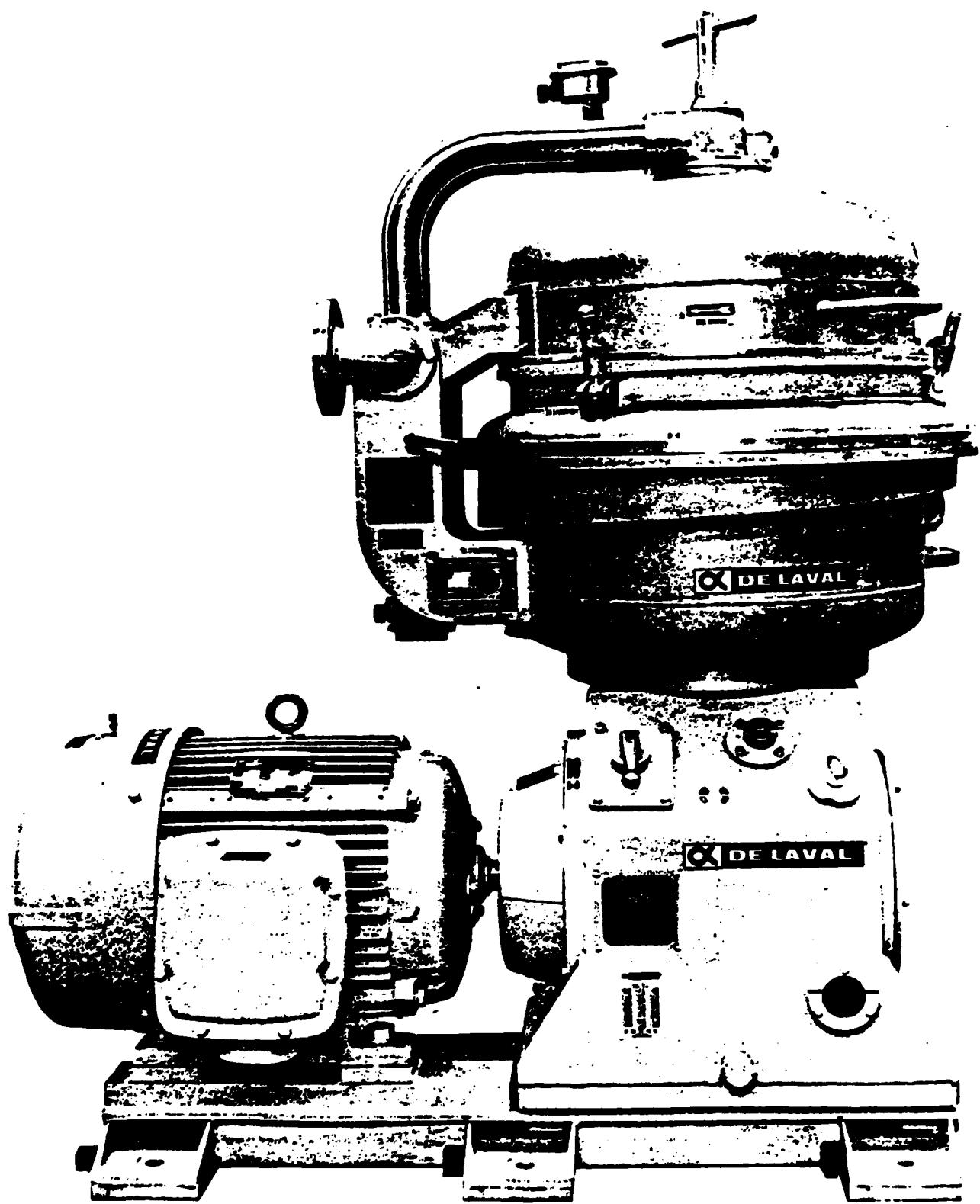
**FIGURE 1**  
**PROGRAM STRUCTURE**



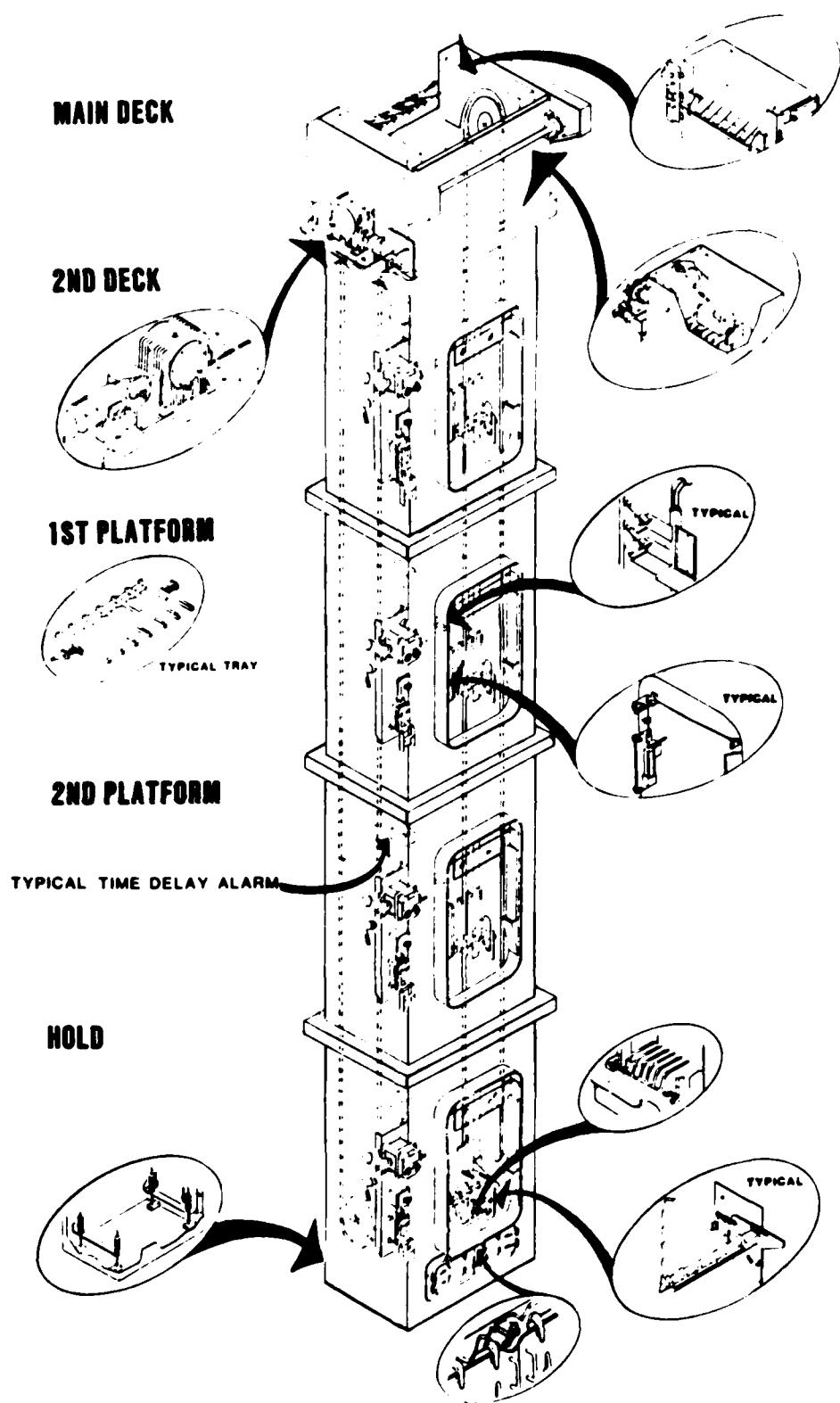
**FIGURE 2**  
**VAPOR COMPRESSION DISTILLER**  
**SYSTEM SCHEMATIC**



**FIGURE 3**  
**HOLLOW FIBER**  
**REVERSE OSMOSIS MODULE**



**FIGURE 4**  
**USPX-413 SELF CLEANING**  
**CENTRIFUGAL PURIFER**



**FIGURE 5**  
**STANDARD VERTICAL**  
**PACKAGE CONVEYOR**

